Commonwealth of Massachusetts

House of Representatives

MASSACHUSETTS DAMS . . .

ARE THEY SAFE?

HPAO
House Post Audit and Oversight

House Post Audit and Oversight Committee

The Commonwealth of Massachusetts

House of Representatives

Committee on Post Audit and Oversight

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TO: THE HONORABLE MEMBERS OF THE HOUSE OF REPRESENTATIVES

As Chairman of the Post Audit and Oversight Committee, I am pleased to present this report on the Massachusetts Dam Safety Program.

The report was developed in conjunction with the University of Massachusetts (Amherst) Department of Civil Engineering. This is the sixth report which has been completed through our Academic Resources Program. The purpose of this program is to afford us access to informed policy perspective and technical competence necessary for evaluating state funded programs.

I wish to express my thanks to Dr. Mario Fantini, Dean of the School of Education at the University and his Special Assistant, Dr. Lynn Cadwallader, who acted as liaisons throughout the study. I would also like to thank Mr. Frank Matrango, Assistant Director of the House Post Audit and Oversight Bureau who conducted the negotiations which led to the involvement of the University and also monitored progress throughout the study.

Robert A. Cerasoli

ROBERT A. CERASOLI
Chairman

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of the

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THE GENERAL COURT OF MASSACHUSETTS
Post Audit and Oversight Bureau
ROOM 146, STATE HOUSE
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RICHARD F. TOBIN, JR.
DIRECTOR

FOREWORD

This report is a prescription for reform of the Massachusetts Dam Safety Program.

It provides an assessment of the program's effectiveness with a focus on its major deficiencies. The report also includes recommended alternatives to resolve those deficiencies.

Dr. Richard R. Noss of the Department of Engineering, University of Massachusetts (Amherst) and his associates are responsible for the text of this report. I would like to thank Dr. Noss whose expertise proved invaluable in the development of alternative methods of achieving the desired result of an effective dam safety program for the Commonwealth.

Further, we express our gratitude to Mr. James Gutensohn, Commissioner of Environmental Management, and his staff for their cooperation during the course of this study.

The Introduction section of the report was prepared by Mr. Dennis Griffin, Assistant Director of the House Post Audit and Oversight Bureau.

Richard F. Tobin, Jr.
Director

INTRODUCTION

> *Dam policy in Massachusetts suffers from a lack of public and official concern. Except for periodic attention to dam safety (which is aroused only briefly after each dam break catastrophe) —, there appears to be widespread lack of concern with Massachusetts' dams.*[1]

The lack of concern for dam safety in Massachusetts which was noted in the 1977 report referenced above still exists today. The purpose of any dam safety program is to prevent the loss of life and property damage associated with dam failures. That goal is not being met in Massachusetts and as a result, the House Post Audit and Oversight Committee has developed a prescription for reform entitled, <u>Improving Massachusetts Dam Safety Inspection Procedures.</u>

According to officials of the Massachusetts Dam Safety Program (MDSP) there are approximately 3,000 dams in Massachusetts of which, it is estimated, 1,500 come under the purview of MDSP. However, that figure is no more than an educated guess because MDSP does not maintain an inventory of dams in the Commonwealth. As a result, dams have not been classified as to their condition and potential for creating the damages and loss of life associated with dam failures.

The following statement taken from a recent report on the subject of dam safety, published by the National Academy of Sciences, capsulizes the importance of government involvement in dam safety and the threat to public safety which exists if government ignores its responsibility in this area.

> *Because of several disasters in recent years, the safety of dams has received increased attention throughout the world. Governments at all levels <u>have come to recognize and</u>, in many cases, <u>to accept their responsibilities</u> in this area. In the United States, federal and state agencies have been active in inventorying and inspecting dams in the interest of improved safeguards. The results point to deficiencies that are widespread and to a problem of national importance. From the disasters and from the evaluations of thousands of dams, the message is clear*

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[1]Edward R. Kaynor, *Dam Policy in Massachusetts,* Water Resources Research Center (University of Massachusetts, 1977), p. 3

that the threat to public safety is large and must be reduced. Although the danger is evident, its elimination will be difficult for at least two principal reasons: those responsible must be ready to take action and the funds for remedial action must be found.[2] [Emphasis added]

Massachusetts has not come to recognize or accept its responsibility. As a result, the threat to public safety remains large and is not being reduced to any appreciable extent.

Hundreds of thousands of dams have been built in this country over the past three centuries. These dams have provided such essential benefits as water supply, flood protection, recreation, energy generation, and irrigation. In the past twenty years, several major dam failures have occurred and as a result there has developed an increased awareness of the potential hazards posed by dams. When a large dam, designed to impound a tremendous quantity of water is constructed upstream of a populated community, a very definite threat to that community from the possible failure of that dam is created.

Dam failure has been described as the catastrophic giving way of a dam, featured by the sudden, swift and uncontrolled release of impounded water. There are degrees of failure, and any malfunction or abnormality which adversely affects a dam's primary function of impounding water is properly considered a failure. A lesser degree of failure could lead to or heighten the risk of a catastrophic failure. Excessive rainfall, runoff increased by snow melting, poor construction or maintenance, earthquakes, or other natural or even human caused phenomena can lead to dam failure.

Dam failures are usually measured in terms of lives lost and damages to downstream property caused by flooding. However, dam failures can cause other problems most of which are water related. A flash flood created by a dam failure could lead to water supply problems, power failures or even the release of hazardous materials.

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[2]National Research Council, *Safety of Existing Dams*, Evaluation and Improvement Committee on the Safety of Existing Dams, Water Science and Technology Board, Commission on Engineering and Technical Systems (Washington, D.C.: National Academy Press, 1983), p. vii

In a 1979 report published by the Water Resources Research Center, University of Massachusetts, the author stated as follows:

> *With over 3,000 reported dams at various locations on many streams of this state — one would expect state dam policy to be well-developed and designed to maximize beneficial uses and to minimize the costs associated with those uses. Such a well-developed set of dam policies has been found lacking.*[3]

Based upon currently available evidence, HPAO concludes that nothing has occurred in the intervening six years which would alter that statement today. For example, the U.S. Army Corps of Engineers in its May, 1982 Final Report to Congress resulting from its inventory and inspection of non-federal dams throughout the United States determined that there were fifty-six (56) <u>unsafe</u> dams in Massachusetts. The term unsafe as used in that report meant that:

a. The spillway could not pass one-half of the probably maximum flood without the dam being overtopped;

b. Such overtopping would probably cause the dam to fail; and

c. Failure of the dam would probably cause loss of life.

Yet, the Massachusetts Dam Safety Program has done little to address this very serious problem in the intervening period. Fewer than ten (10) of those dams have had any repair work done on them despite the fact that the Corps recommended that remedial measures be taken within one to two years after its report. This period was probably recommended since none of the unsafe Massachusetts dams were placed in the "emergency" category (this would have required immediate repairs) by the Corps but were instead categorized as "non-emergency".

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[3]Kaynor, *Dam Policy in Massachusetts*, p. 1

THE PROGRAM

Massachusetts does not have an effective Dam Safety Inspection Program. The Program must be reformed if that agency is to accomplish its goal. The existing program is deficient in at least three major areas:

1. Staffing and Expertise
2. Funding
3. Commitment

1) Staffing and Expertise — MDSP, although budgeted for four employees, currently is operating with only three and, of these, two actually go into the field in order to inspect dams.

Although the three employees are filling job titles which include the term "engineer", none is a registered professional engineer. In order to do the job of inspecting dams properly, the agency must have professional engineering expertise. The type of inspection performed by MDSP personnel today is strictly a visual inspection because MDSP has no capability to go beyond that. In a 1983 evaluation report prepared for the State of Connecticut on its Dam Safety Program, a consulting firm recommended "a technical staff consisting of approximately 17 engineers, technicians and administrative assistants."[4] This was for a state which has a comparable number of dams to Massachusetts, approximately 3500.

2) Funding — The Massachusetts Dam Safety Program operates on an annual budget of approximately $115,000 dollars allocated to it from the maintenance budget of the Department of Environmental Management. This amount is not sufficient to get the job done. MDSP staff are visually inspecting some 200 dams annually. At this rate it will take seven and one-half years to inspect the 1500 dams which come under MDSP's purview. The inspections done are basically superficial and are not of a quality which will discover deficiencies which are not readily apparent. The previously cited 1983 report prepared on Connecticut's Dam Safety Program recommended an annual budget of $612,000 dollars for Connecticut's program. California has one of the oldest and most comprehensive dam safety

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[4]Connecticut Dam Safety Program Evaluation Report, PRC Harris, Consulting Engineers, January 1983, Chapter 7

programs in the nation. While we recognize that California is much larger than Massachusetts and has had more seismic activity which adversely affects the stability of dams, we must point out that California's dam safety program operates on an annual budget in excess of $3,000,000. In addition, California's field engineers are all registered civil engineers.

3) Commitment — HPAO must question the commitment to the Dam Safety Program in Massachusetts. Legislation enacted in 1979 authorized the Commissioner of Environmental Management to promulgate regulations which would classify dams according to the potential for damage to life and property. Six years have passed and no such regulations exist. Further, according to the statute, every dam was to be inspected according to a schedule established by those regulations. No regulations exist, therefore there is no such schedule.

Furthermore, the small number of visual inspections which are accomplished each year result in no follow-up to ascertain if the dam owners are complying with the findings and recommendations contained in the reports which result from the rather cursory visual inspections performed by the MDSP staff.

In addition, despite the recommendation contained in the Federal Guidelines for Dam Safety, prepared by the Ad Hoc Interagency Committee on Dam Safety of the Federal Coordinating Council for Science, Engineering and Technology published in June of 1979, that dam inspections be made no less than every five years, MDSP is not, and has not come close to, maintaining such a schedule. One of the major reasons for this situation is the fact that MDSP does not have an accurate inventory of the dams which fall under its purview. Although there has been a recent effort by MDSP to develop such an inventory through the state's Civil Defense Agency, thus far there has been little progress.

According to a recent publication of the National Association of Conservation Districts, thirty-nine (39) states have adequate legislation authorizing dam safety programs, yet only sixteen (16) provide the regulatory procedures, technical staff and funds necessary to carry out effective programs. Our review of the Massachusetts Dam Safety Program can lead only to the conclusion that Massachusetts is not one of those sixteen states.

HISTORY

Massachusetts has been quite fortunate. We have not had a major dam failure since March of 1968 when a dam at Lake Lee, in the town of Lee, burst on a Sunday releasing an estimated 12 million gallons of water, which killed two individuals and destroyed homes, businesses and roads and did $12 million dollars in damage. The dam was a three-year-old earthen structure which had been constructed in order to impound water for a leisure-home development. The dam was 475 feet long and 25 feet high and was 10 feet wide at the top. When the break in the dam came, 12 million gallons of water poured into East Lee from a 40-acre lake.

As a result of this catastrophe, control of all non-federal dams in the State was transferred from the county commissioners to the State's Department of Public Works in 1970. It has since been transferred twice, now residing in the Department of Environmental Management. However, it seems that each succeeding transfer has served to further weaken the program in terms of staffing, expertise, funding and commitment.

The Governor, at the time of the disaster, on a visit to the site was quoted, in reference to the State's dams, as follows:

> "I think they should be listed and regulated by one agency and the state is the proper authority."[5]

We find that 17 years later the agency established in response to that call does not even maintain an inventory of the dams for which it is responsible.

The U.S. Army Corps of Engineers, in its final report to Congress, dated May 1982, which resulted from its National Program of Inspection of non-federal dams, included a series of tables containing data developed during the course of that five-year effort. An HPAO analysis of that data strongly supports the conclusion that the Massachusetts Dam Safety Program has not been effective.

For example, the report included a table which contained the Corps of Engineers categorization of the nine attributes which were necessary for a complete dam safety program. Each state was rated as to how

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[5] *Berkshire (Mass.) Eagle*, 27 March, 1968

many of those nine attributes were present in its program. Massachusetts was rated adequate in two of the nine categories. Only three of the fifty states received lower adequacy ratings.

Also, contained in the final report to Congress was another table entitled Remedial Measures for Unsafe Dams. The purpose of this table was to indicate the type of remedial measures, if any, which had been undertaken to correct deficiencies in dams which had, during the course of the Corps' study, been identified as unsafe. The term unsafe as used in this report meant that the dam had "deficiencies of such nature that if not corrected could result in failure of the dam and subsequent loss of human life and property damage." Each state was notified as to how many of its dams had been determined as unsafe. This was done prior to 1981. The States were requested to respond one year later to the Corps of Engineers as to the extent and type of remedial measures which had been undertaken to correct the unsafe conditions. Of those states which had more than five (5) dams categorized as unsafe, Massachusetts, which had 56 such unsafe dams, was one of only two states [New Hampshire, with 12 unsafe dams, was the other] to reply that no remedial measures had even been initiated. As a comparison we selected the state of South Dakota which had been notified of 57 unsafe dams resulting from the Corps' study. In responding to the follow-up done by the Corps, South Dakota officials indicated that repairs had been completed on six of the unsafe dams and that repair work was initiated on the remaining fifty-one.

CONCLUSION

The goal of this report is the enhancement of dam safety in Massachusetts within the State's financial restraints. It is, very simply, a prescription for the reform of a program which is seriously ill.

As the previously cited National Research Council report states:

> *The resolution of dam safety problems requires an understanding not only of technical questions but also of complex financial and institutional problems. In the competition for limited public funds, a dam safety program is often seen as one of many worthwhile but expensive hazard mitigation programs.*[6]

HPAO recognizes that in programs involving public safety there are always trade-offs between cost and risk and that no matter how much money is spent, some unknown risk will remain. However, the identification and improvement of deficient dams must begin without delay, even though immediately available funding may be insufficient for a comprehensive solution.

It should not be forgotten that, if the dam break in Lee in 1968 had occurred on a week day, the lives of the 120 employees of a manufacturing plant which was totally destroyed in the resulting flood, would have been threatened. Nor should it be forgotten that Massachusetts had fifty-six unsafe dams four years ago and that it can be assumed that in the interim, many others have deteriorated to the point where they would now be classified as unsafe.

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[6] *Safety of Existing Dams*, p. 43

IMPROVING MASSACHUSETTS DAM SAFETY
INSPECTION PROCEDURES

By

Richard R. Noss, Edwin J. Fleischer,
Ching S. Chang and Shaw-Wei Duann

IMPROVING MASSACHUSETTS DAM SAFETY INSPECTION PROCEDURES

FINAL REPORT

to

Post Audit and Oversight Committee
of the
Massachusetts House of Representatives

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*NOTE: Pagination is correct. Exhibit 8 is on a page by itself.

Acknowledgements

This study was coordinated through the Academic Resources Program at the University of Massachusetts/Amherst. The Academic Resources Program was established by the House Post Audit and Oversight Bureau to make the expertise and resources of the university available to conduct studies and provide information to the Post Audit and Oversight Committee of the Massachusetts House of Representatives as it evaluates state programs. We gratefully acknowledge the assistance of Lynn Cadwallader in arranging and facilitating our work with the House Post Audit and Oversight Bureau. We also wish to acknowledge the guidance and critical review of Frank Matrango, Assistant Director of the House Post Audit and Oversight Bureau. The assistance of Mr. Joseph Iagallo, Program Manager of the Massachusetts Dam Safety Inspection Program is also appreciated.

Finally we wish to express our thanks to Mrs. Dorothy Pascoe whose patience and word processing skill have made this report a reality.

Chapter 1

Introduction

Massachusetts has been fortunate. No major dam failures have occurred for over 15 years. This is not to imply that Massachusetts' dams are in good shape. The fact of the matter is that no one really knows.

This report presents our findings and recommendations on four aspects of the Massachusetts Dam Safety Inspection Program:

1) Staffing
2) Dam Safety Inspection Procedures
3) Dam Inventory and Data Management
4) Use of Hazard Ratings to Prioritize Inspection Activities.

The purpose of a state dam safety program is to minimize the risk to the public of the damages and loss of life associated with dam failures. This must be done within the constraints imposed on the program - such as manpower, expertise, resources, etc. No program, no matter how large or how expensive, can eliminate these risks entirely.

ORIGIN OF THIS REPORT

This study traces its roots to a series of contacts starting in July 1983 between staff of the House Post Audit and Oversight Bureau and the University of Massachusetts/Amherst faculty with interests in infrastructure management and rehabilitation. Professor Richard R. Noss of the Environmental Engineering Program in the Department of Civil Engineering was identified as a lead faculty member in a study of how to upgrade the quality of the Massachusetts Dam Safety inspection procedures.

The focus of the study was to be a report to the legislature on program needs, not an attempt to dictate to the executive branch how to run one of its programs. As this report was being written the State Auditor's Office released an evaluation of the Massachusetts Dam Safety Inspection Program.[7] At the risk of oversimplifying, the Auditor's report differs from this report in that it concentrated primarily on an audit of day to day operations.

This report addresses three substantial deficiencies in the Massachusetts Dam Safety Inspection Program: dam inspection procedures, program staffing, and prioritization of dams for subsequent inspections. Dam safety inspection procedures proposed and used by expert advisory groups and federal, state and regional agencies were evaluated. These inspection procedures were distilled into one inspection protocol for Massachusetts dams and conditions. Similarly, the personnel needed to provide the expertise necessary to conduct the inspections outlined in the protocol were determined. The content of the dam inspection and the qualifications of the inspection personnel are the essence of a dam inspection program. The Massachusetts Dam Safety Inspection Program also needs better administrative procedures, oversight and follow-through on the results of inspections, but without comprehensive inspections by qualified personnel the program will only catch the most outstanding deficiencies. This report concentrates on the inspection procedures and staffing in the belief that these are the most serious deficiencies in the existing program. Improvements in the administrative procedures, such as those recommended by the State Auditor's report, are also needed to maximize the overall efficiency and utility of the program.

The third portion of this report presents a dam safety risk assessment methodology to rank dams according to the risk they pose to downstream persons and property. When a complete inventory of Massachusetts dams is available, the risk assessment methodology can be used to confirm the estimates used in this report to prepare the staffing requirements. More importantly the ranking produced by the risk assessment methodology can be used to assure that those dams with the greatest Risk Factor will receive the earliest and most frequent inspections.

HISTORY OF DAM INSPECTION IN MASSACHUSETTS

Chapter 253 of the Massachusetts General Laws provides the legislative authority for the regulation of dams in Massachusetts. The responsibility for dam inspections and the regulation of dams has been shifted several times, however; the net result has been a loss of resources devoted to the program and a reduction in the program's effectiveness and its ability to perform its assigned functions.

The Massachusetts dam safety inspection program was initiated in 1854 when the General Court assigned inspection responsibilities to the County Commissioners. Dam inspection responsibilities were transferred to the Department of Public Works (DPW) in 1970 by Chapter 595 of the Acts of 1970 (amending MGL Ch. 253). The DPW operated the inspections out of eight district offices each of which had two dam inspection engineers. Two hydrologists in the Department's Division of Waterways in the Boston Office provided additional expertise.

The Division of Waterways, and with it the responsibility for dam safety inspections, was subsequently transferred to the Department of Environmental Quality Engineering (DEQE) as part of the 1974 Department of Environmental Affairs Reorganization Act (Ch. 806, Acts of 1974). The dam inspection staff was not transferred however. DEQE staffed the program with an administrator, one assistant civil engineer and one junior engineer. The program shared secretarial services with the rest of the Waterways Division.

More recently the dam inspection program has been transferred to the Department of Environmental Management, first as a budget transfer in 1983, and then by legislative act in July 1983 (Chapter 589 of the Acts of 1983).

The net effect of this series of reorganizations has been to decimate the staff and effectiveness of the dam safety program. Although the inspections performed by the county staff lacked the rigor and technical evaluations which are part of the inspection protocol recommended later in this report, the dams were at least being visited and visually inspected. The program, with its current staffing, cannot achieve even this level of performance, much less implement the recommendations presented later in this report. The bulk of the information on dam ownership and condition in the program's files dates to the times when dam inspections were performed by the counties and the Department of Public Works.

The Massachusetts Dam Safety Inspection Program has never been guided by written regulations. Chapter 722 of the Acts of 1979 required the Commissioner of DEQE to prepare regulations to implement provisions of the M.G.L. Chapter 253 dam construction, maintenance and inspection program. Chapter 722 specifically required the regulations to classify dams according

to the potential for damage to life or property (i.e., risk assessment). According to the Program Manager of the Dam Safety Inspection Program regulations are currently "under preparation."[6] There is no material evidence of progress toward promulgation of the regulations at this time.

FEDERAL ROLE

The federal government has also had a role in the inspection of dams in Massachusetts. The National Dam Inspection Act of 1972 (PL92-367) directed the Corps of Engineers to inventory all non-federal dams which

1) are greater than 25 feet in height,

or

2) impound at least 50 acre feet of water at their maximum storage capacity.

(Except dams less than 6 feet high are excluded no matter how much water they store. Also, dams storing less than 15 acre feet of water are excluded no matter how high the dam is.) The dams included and excluded by the above criteria (specified in PL 92-367) are illustrated in Exhibit I.

The Corps' work was conducted in two phases. The first phase concentrated on the preparation of a model state dam inspection program. An inventory, by state, of dams meeting the above criteria was prepared from existing information. In the second phase the Corps conducted actual inspections of a sample of dams in each state. The Corps inventoried 1151 dams in Massachusetts meeting the above criteria. Of these 1151 dams, 369 were visually inspected by the Corps or their consultants between 1978 and 1981. These 1151 dams are further characterized in Exhibit II.

Exhibit I

Dams Included and Excluded by PL 92-367

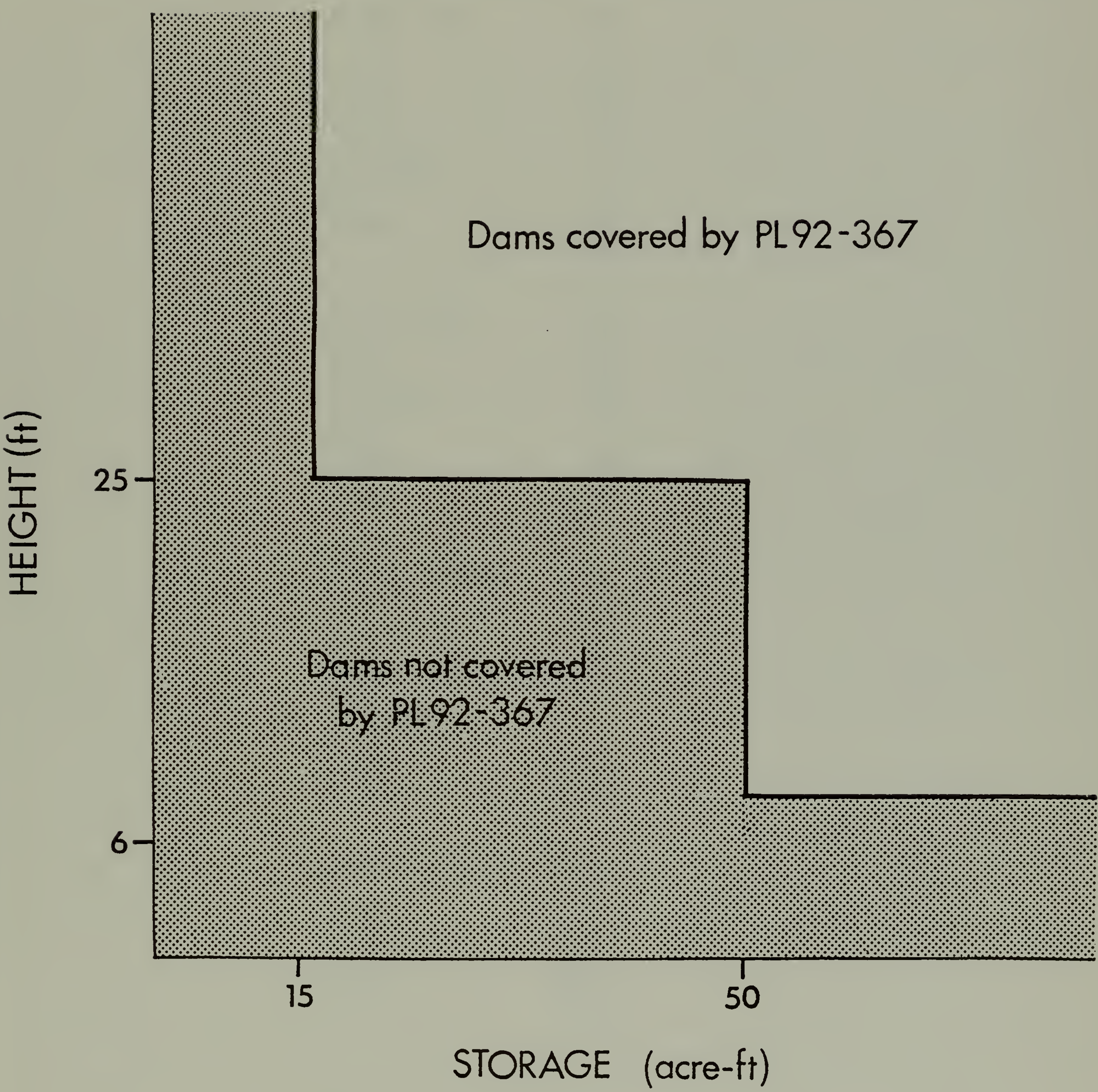


Exhibit II

Characteristics of Massachusetts Dams Inventoried by the Corps of Engineers

Height (ft)	No.
7-24	870
25-39	177
40-99	88
100-199	12
200-299	4
300	0
TOTAL	**1151**

Type of Dam	No.
Earth	881
Gravity	175
Rockfill	75
Arch	5
Other	15
TOTAL	**1151**

Major Purpose	No.
Recreation	549
Water Supply	298
Flood Control	109
Irrigation	106
Hydro-electric	38
Other	51
TOTAL	**1151**

Hazard Rating	No.
High	245
Significant	425
Low	481
TOTAL	**1151**

The Corps also tried to prepare the states to implement effective state dam safety programs. The Corps recommended that states:

(1) Review and approve plans and specifications to construct, enlarge, modify, remove, or abandon dams.

(2) Perform periodic inspections during construction for the purpose of insuring compliance with approved plans and specifications.

(3) Upon completion of construction, issue certificates of approval permitting the impounding of water.

(4) Investigate dams and reservoirs at least every five years to determine their continued safety.

(5) Issue notices, when appropriate, to require owners of the dams and reservoirs to perform necessary maintenance or remedial work, revise operating procedures, or take other actions, including breaching dams when deemed necessary.[15]

The Corps' Phase I report (completed in 1975), National Program of Inspection of Dams (Appendix D), evaluated state dam safety programs with respect to their recommended program.[12] Sixteen states had developed programs which were completely adequate. Massachusetts' program was found inadequate in eight of the ten attributes evaluated. (See Exhibit III).

CURRENT MASSACHUSETTS REQUIREMENTS

The current Massachusetts dam safety inspection program is governed by MGL, Chapter 253, Sections 44-47. These sections:

-define the dams that fall within the purview of the Act,

-require that regulations to implement the Act be promulgated,

Exhibit III

Excerpt from Corps of Engineers Evaluation of State Dam Safety Programs (from Reference 12)

Attributes
(* Indicates Adequate)

	State	Dam Safety Legislation	Review of Design Plans & Specs.	Inspection During Constrctn	Issuance of Impounding Permits	Periodic Inspection of Compltd Projects	Rqrmnts for Remedial Measures	State Funding	Technical Staffing	Planned Future Program	Existing Program
14.	Indiana	*	*			*	*	*	*	*	
15.	Iowa	*	*	*	*	*	*		*	*	
16.	Kansas	*	*		*		*			*	
17.	Kentucky	*	*	*	*	*	*	*	*		*
18.	Louisiana	*	*	*	*	*	*			*	
19.	Maine		*				*				
20.	Maryland	*	*	*	*	*	*	*	*		*
21	Massachusetts	*					*				
22.	Michigan	*	*	*	*	*	*			*	
23.	Minnesota	*	*	*	*	*	*		*	*	
24.	Mississippi	*	*				*				
25.	Missouri		*	*	*	*	*				
26.	Montana										

-require that dams be classified according to the potential for damage to life or property,

-set forth requirements for licensing of new dams,

-require the Commissioner [of DEM] to inspect each dam visually according to a schedule established in the regulations, and

-establish procedures and authority for taking remedial and emergency actions.

Section 44 (as amended by Chapter 722 of 1979) defines a dam for the purposes of the Act as "any artificial barrier...which impounds or diverts water and which...

1) is twenty-five feet or more in height...

or

2) has an impounding capacity at maximum water storage elevation of 50 acre-feet or more."

Except that

1) dams less than 6 feet high are not covered regardless of their storage, and

2) dams impounding less than 15 acre feet are not covered regardless of their height.

This definition conforms exactly with the federal definition found in Section 1 of PL 92-367. The Corps report identifies 1151 dams in Massachusetts that meet this definition. In addition,

"Any other dam, the breaching of which could endanger property or safety which is designated by the commissioner under criteria established by regulations promulgated by the commissioner shall be subject to the provisions of [the Act]."

The Program Manager of the Massachusetts Dam Safety Inspection Program estimates that another 300-400 dams would be added by this provision to the 1151 identified by the federal definition alone.[6]

Thus, of the estimated 3000 dams in the state, approximately half fall under the purview of the Massachusetts dam safety program.

DAM SAFETY INSPECTIONS

A review of five studies covering a total of 1290 dam failures worldwide found that failures could be attributed to three primary causes:

1) overtopping or spillway inadequacy
2) piping or seepage
3) other (poor construction, earthquake effects, excessive deformation, slides, etc.).[2]

Approximately one-third of the failures have been associated with each mechanism. A good inspection should be able to identify potential problems associated with inadequate spillways or seepage before the problems become critical. Some of the components of the third category are also identifiable in advance.

Of the 369 dams actually inspected by the Corps in Massachusetts, 56 (or 15.2%) were deemed unsafe.[15] Multiple inadequacies were found in most cases. Spillway inadequacies were identified in 55 of the 56 dams deemed unsafe. The second most common deficiency identified was excessive seepage. Both of these inadequacies are readily identified in dam inspections.

Chapter 2

Dam Inspection Protocols

STATE OF THE ART

Dam safety inspection procedures must reconcile two conflicting objectives: 1) Inspect each dam as frequently as possible and 2) Make each inspection as thorough as possible. The more frequently inspections are scheduled, the less detailed each inspection can be, since dam safety inspection protocols are directly affected by the resource constraint referred to in Chapter 1.

In general, the approaches to dam safety inspections may be considered as: 1) Same inspection each time for each dam with varying frequency depending on the categorization of the dams; 2) Different inspections for different dams depending on the categorization of the dams; and 3) Different inspections and different frequencies.

Nine major federal and state agencies with recognized expertise on dam safety inspections were surveyed to provide information on how they balanced frequency of inspection against inspection detail. (See Exhibit IV.) Some examples follow.

<u>The U.S. Bureau of Reclamation</u>, builder and operator of numerous dams in the Western U.S., classified the safety inspections into two types: Regular examinations and 6-year examinations.[16] The 6-year examination is characterized by an emphasis on a fresh look at the safety of the dam and appurtenant features and a comparison of the dam against the project design. Regular examinations are conducted at least once every two years during the interval between 6-year examinations and are less intensive than 6-year

Exhibit IV.

Agencies Providing Information on Dam Safety Inspections

1. Texas Department of Water Resources
2. California Department of Water Resources
3. Federal Energy Regulatory Commission
4. Department of the Army, Corps of Engineers
5. Tennessee Valley Authority
6. Idaho Department of Water Resources
7. U. S. Bureau of Reclamation
8. Pennsylvania Department of Environmental Resources
9. National Research Council

examinations. The 6-year examinations are conducted by a multidisciplinary team including several engineers and a geologist. The regular inspections may be by a single inspector for low hazard dams. (Bureau of Reclamation dams are relatively large dams.)

The Tennessee Valley Authority (TVA) conducts four types of inspections: 1) Formal inspections, 2) Intermediate inspections, 3) Informal inspections, and 4) Special inspections.[10,11] A formal inspection may be defined as a detailed inspection of the dam, appurtenant structures and equipment, including diving inspections of underwater structures. Intermediate inspections are less intensive than formal inspections. Intermediate inspections are also thorough field inspections of the dam and appurtenant structures by appropriate specialists. The purpose of informal inspections is to have, as far as practicable, a continuous surveillance of dam safety-related elements. The informal inspections are conducted by operating employees and maintenance workers. The TVA's inspections are described further in Exhibit V.

The National Research Council (which is the operating arm of the National Academy of Sciences, National Academy of Engineering and the Institute of Medicine) proposed a three-part inspection program: 1) Formal technical inspections, 2) Formal maintenance inspections, and 3) Informal observations.[8] Technical inspections are those involving specialists familiar with the design and construction of dams and include an assessment of the safety of the project structures. Maintenance inspections are those performed at a greater frequency than technical inspections in order to detect any significant developments in project conditions at an early stage. Maintenance inspections involve consideration of operational capability as

Exhibit V.

Dam Safety Inspection Program of TVA

1. Formal inspections

   a. Frequency
      Made periodically at intervals not to exceed 5 years, except less frequent inspections may be permitted for some features not directly related to the safety of the dam
      As much as 10-year intervals are allowed for some features such as penstocks and powerhouse not constructed as an integral part of the dam
      Depending on past experience or the project history, some dams may require more frequent formal inspections

   b. Personnel
      The inspection team is comprised of technically qualified individuals having appropriate specialized knowledge in structural, mechanical, electrical, and hydraulic features of the project and knowledgeable and trained in inspection procedures.

2. Intermediate inspections

   a. Frequency 30 months following the previous formal inspection or approximately 5 year intervals

   b. Personnel
      The same as formal inspections
      The plant superintendent or his appointed representative is an active participant.

3. Informal inspections

   a. Monthly basis
      Made immediately after any unusual event such as large floods, earthquakes, suspected sabotage or vandalism

   b. Personnel
      Personnel who can recognize abnormal conditions

4. Special inspections

   a. Frequency
      Performed as soon as possible after the dam has passed unusually large floods and after the occurrence of a significant earthquake or sabotage
      Also after unusual events reported by operating personnel

   b. Personnel
      Same as formal inspections

well as structural stability. The third type of inspection is actually a continuing effort performed by on-site project personnel in the course of performing their normal duties. Additional information on the National Research Council's recommendations is presented in Exhibit VI.

The frequency of inspection for a given dam often is related to its hazard potential. The U.S. Army Corps of Engineers used three levels of hazard potential in their work: low, significant and high. These are defined in Exhibit VII. These classifications are now generally accepted by dam safety officials. All of the above dam safety inspection programs have different types of inspections at different time intervals which may be affected by the hazard potential of dams.

The protocols associated with each type of inspection are different. Some of them can be done by a trained inspector while some require the knowledge of specialists. The degree of importance of each inspection item to the safety of a dam is quite different. A trained dam inspector should be able to make at least a cursory evaluation of each item in the inspection protocol. The more technically trained the inspector, or, more likely, the more specialists on the inspection team, the better the evaluation will be. Thus the quality of the inspection is varied not by varying the inspection protocol but by varying the expertise of the dam inspection team. Using the same protocol each time will help to remind the inspectors to at least check for obvious deficiencies in each of the items.

Inspection protocols are usually classified by the two major types of dams: Embankment dams and Concrete dams. The main inspection categories for

Exhibit VI.

Dam Safety Inspection Program Recommended by the National Research Council

1. Technical inspections

   a. Frequency
   New dam or reconstructed dam or a dam that has not been properly inspected by experts for some years -- Semiannual
   As inspectors become more familiar with the dam, and adequate data has been compiled -- Once per year or once in two or more years depending on the hazard rating but no more than once in 5 years
   Variable operating conditions(e.g. Reservoir level down, full or preferably spilling)

   b. Personnel
   One independent civil engineer (not a member of the owner's staff,and who preferably has over 10 year experience in the design and evaluation of dams)
   One geologist (on initial inspection and at about 5-year intervals on others, particularly where problems relating to geology are suspected or known to exist)

2. Maintenance inspections

   a. Frequency
   Semiannual-to-annual

   b. Personnel
   An engineer or experienced supervisor of dam operations

3. Informal observations

   a. Frequency
   During routine maintenance activities

   b. Personnel
   Operators, maintenance crew members and all others, including the owners of small dams

Exhibit VII.

Hazard Potential Classification

Category	Loss of Life (Extent of Development)	Economic Loss
Low	None expected (No structure for human habitation)	Minimal (Undeveloped to occasional structure or agricultural)
Significant	Few (No rural communities or urban developments and no more than a small number of habitable structures)	Appreciable (Notable agriculture, industrial, or community)
High	Urban development with more than a small number of habitable structures)	Excessive(extensive community, industry or agriculture)

each type of dam are:

1. Embankment (earth or rockfill) dam

   Dam
   Spillway
   Outlet works
   Power features
   Reservoir
   Access road
   Geology

2. Concrete dam

   Dam
   Abutments
   Spillway
   Outlet works
   Power features
   Reservoir
   Access road
   Geology

The protocols recommended here for the two types of dams are listed in Appendix A (page 57). If the dam is a hybrid dam, the protocols should be combined.

REVIEW OF CURRENT MASSACHUSETTS DAM SAFETY INSPECTION PROCEDURES

The Massachusetts dam safety program currently uses an ad hoc inspection procedure based on a check list to guide the inspections. The check list includes:

1. Name, number and location of dam
2. Previous inspection date
3. Name, address and telephone number of owner and/or dam caretaker
4. Type of dam, controls, spillways, wing walls, face of dam, down slope of dam, condition of dike, presence of trees or brush on embankments, signs of erosion, animal burrows, leakage(types),

dislodgement of stones or blocks of dam proper, history of over-topping, and etc.

Finally two overall judgements of the condition of the dam are recorded: either poor, fair or good, and safe or unsafe.

Until recently the program only reported serious deficiencies to dam owners. Since December 1983, all owners are notified by mail of inspection results and those with deficiencies are asked to notify the program in writing when the deficiencies have been corrected.

The inspection check list is standard and is used for all dams. The proposed protocol in Appendix A would greatly expand this checklist in both scope and detail.

Chapter 3

Dam Safety Risk Assessment

Most dam inspection programs specify different frequencies of inspection for dams based on the degree of hazard they present and/or based on the level of detail of the inspection. Chapter two presented information from several existing dam inspection programs on different levels of inspections (formal technical, informal, etc.) and on different levels of hazard (e.g.-at least once every six years, more frequently for high hazard dams). These approaches only work if the hazard potentials of all the dams are known and if the dam inspection resources are available to meet the specified inspection frequencies.

This chapter develops a risk assessment methodology which can be used to classify Massachusetts' dams according to their potential hazard. The term risk as used here includes both the magnitude of the losses resulting from a dam failure and a qualitative assessment of the likelihood of such an event occurring. Characteristics of the dam itself and previous inspection results are used as surrogates for the latter. The magnitude of the losses which might occur is based in large part on the hazard potential of the dam. The hazard posed by a dam is evaluated solely by looking at downstream habitation and development. Thus our concern here is with risk assessment, not hazard assessment.

The risk assessment methodology also provides a ranking of dams which can be used to prioritize inspections if sufficient resources are not available to inspect all dams as frequently as desired. The methodology uses readily available information, including the results of past and future

inspections. The risk assessment methodology will be especially easy to use when combined with the data management/inventory system described in the recommendations of this Report: (Chapter IV). This chapter describes the development and use of the risk assessment methodology. Its implementation is presented in the recommendations in Chapter IV.

RISK ANALYSIS AND HAZARD ASSESSMENT

Historically, engineering decisions were based primarily on good judgment and past experience. Today, regulatory agencies are often faced with the task of applying these principles to make a large number of decisions at one time. This is the case when one is trying to prioritize or rank dams for inspection purposes. The regulatory decision makers find themselves in possession of more information than they can organize or process on the basis of their own judgment or past experiences. When large amounts of information need to be organized and processed, a decision making tool is needed. In regards to dam safety inspections, this tool is a risk assessment procedure.

Risk assessment can be conventiently categorized in three ways[8]:

1) Subjective Assessment
2) Formal (Qualitative) Assessment
3) Index Based (Qualitative) Assessment.

Subjective Assessment is the traditional approach, usually involving one individual or a group of individuals who are thoroughly familiar with a problem and are able to use their collective judgment and experience to arrive at a solution. As stated earlier, in the case of dam safety, it is

unlikely that regulatory officials could afford the time to acquaint themselves with all the dams in a given system.

Formal Qualitative Risk Assessment often uses the mathematical tools of probability and statistics. There are at least three steps to the procedure. The first step is to identify potential causes of failure and calculate the probability of their occurrence. The second step is to evaluate expected losses given a dam failure. The third step is to consider the costs and benefits of alternative means of reducing risk. Frequently, this type of method requires the use of more data than is readily available to the regulatory official.[3] Formal (Qualitative) Risk Assessment procedures are unnecessarily complicated for the task of prioritizing dams for inspection.

An Index Based Qualitative Assessment procedure involves the assignment of numerical weighting factors to various aspects of dam safety which should be considered. Each dam in a group is scored according to the same procedure and the scores are used to rank or prioritize the dams for inspection. It is considerably easier and faster to use than formal methods and lends itself to computerization using "off-the-shelf" software. The required information is contained in existing records such as the U.S. Army Corps of Engineers' Phase I inspection reports, the U.S. Army Corps of Engineers' National Dam Inventory, and the Massachusetts Dam Safety Program's own records. An Index Based Risk Assessment procedure is most appropriate for the purposes of this report.

It is important to remember that a risk assessment is no substitute for good engineering judgment or for a strong dam inspection program. Risk assessment rankings do not identify whether dams are safe or unsafe. Risk

assessment is merely a tool to aid in the decision making process. It is a first step in a dam inspection program. The dams in question still need to be carefully inspected at regular intervals and the risk assessment ranking needs to be revised in accordance with the findings of these inspections.

AN INDEX BASED RISK ASSESSMENT PROCEDURE FOR MASSACHUSETTS

There is no universally accepted risk assessment methodology. Risk assessment methodologies must be individually designed for each application and set of conditions. Civil engineers and designers who have spent their entire careers in the area of dam design and safety are unlikely to agree on the relative importance of various safety criteria. In developing an index based risk assessment procedure suitable for use in Massachusetts, one of the priorities was to use as much existing data as possible. The procedure relies heavily on the Army Corps of Engineers (COE) Phase I Inspection Reports, the Corps' National Dam Inventory, and the Massachusetts Dam Safety Program's own records. Using this information, it is possible to do an initial ranking of the risk associated with each of the state's dams without leaving the office or having to search for additional information. Seven factors were chosen on which to base the risk assessment:

1) Age
2) General condition
3) Seepage
4) Capacity
5) Height
6) Hazard Potential
7) Spillway Adequacy

Each dam is given a score from zero to nine in each category, with the exception of hazard potential which is given extra emphasis with scoring from four to twelve. The scores for each dam are totaled. The dams with the highest scores pose the greatest risk based on the dam characteristics, the dam's condition, and the potential for downstream damages.

This risk assessment method was developed by combining procedures currently used by the U. S. Bureau of Reclamation with the guidelines used by the Corps of Engineers in their Phase I inspection reports.[8,12] Some aspects of the Bureau of Reclamation procedures are eliminated or modified so that they would better apply to the Massachusetts setting. Specifically, it was assumed that seismic activity is relatively constant throughout the state so that category was eliminated. Some numerical values were altered to reflect the fact that Massachusetts has few extremely large dams, unlike the Bureau of Reclamation projects in the western states. Emphasis on hazard potential was also increased. Exhibit VIII is a flow sheet illustrating each category and the various subcategories which contribute to the ranking process. The following pages explain the use of this system and the basis of the scoring within each category.

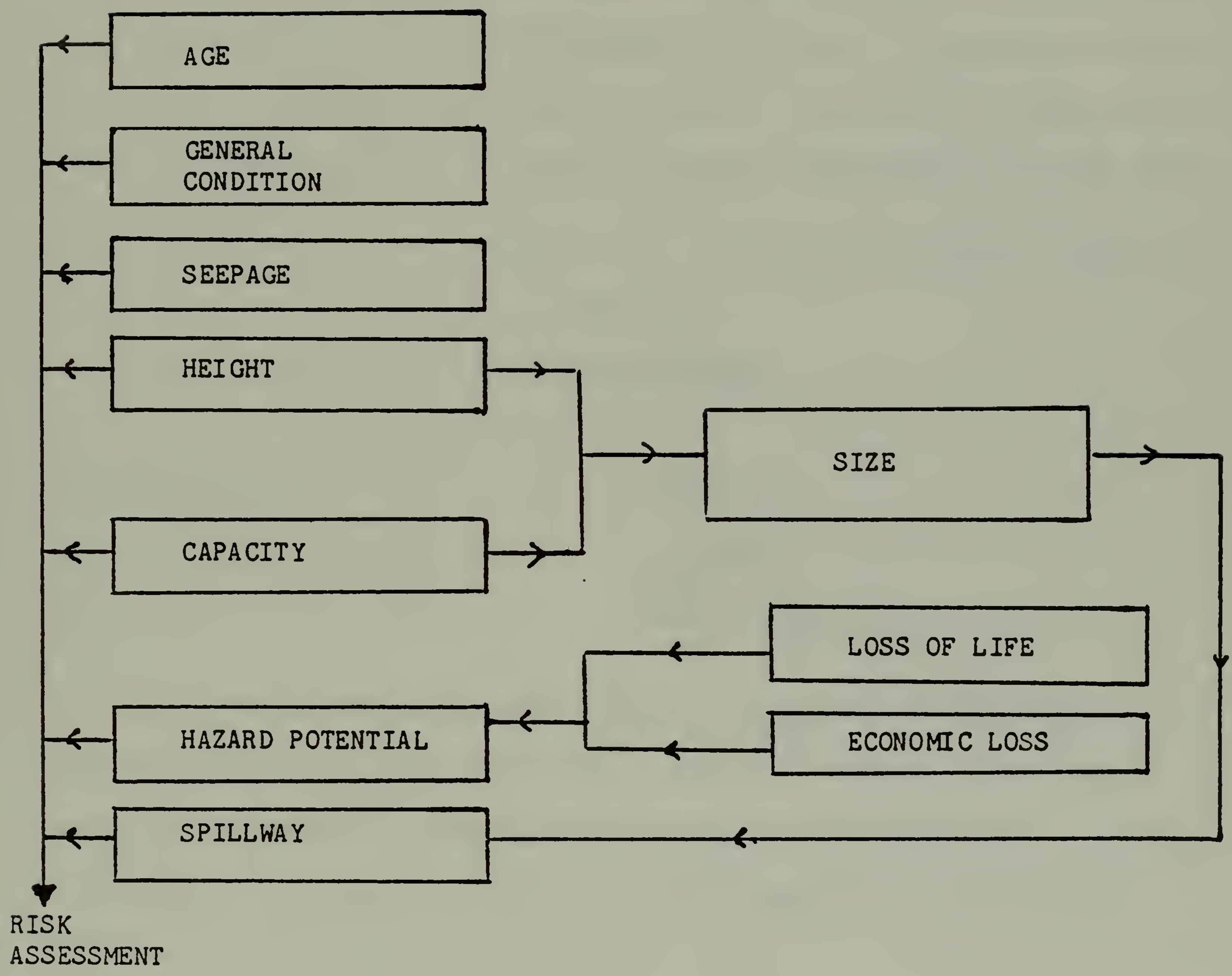
Exhibit IX

AGE CLASSIFICATION

Weighting Factor	Age (Years)
(9)	0-5
(3)	6-24
(4)	25-29
(5)	30-34
(6)	35-39
(7)	40-44
(8)	45-49
(9)	50+

Exhibit VIII

Risk Assessment Flow Sheet



The weighting factors used in the Age classification are shown in Exhibit IX. The age of a dam can be found from either Division of Waterways files or from the National Dam Inventory.[13] Most dams in Massachusetts are older so they score high in this category. The reasoning is that an older dam is more likely to suffer from neglect, therefore, it should be inspected more often. However, extra weight is given to dams which are less than five years old because a study of 1290 dam failures nationwide found that about half of all dam failures occurred within the first five years of operation.[2]

Exhibit X

GENERAL CONDITION

Weighting Factor	Condition
(0)	Excellent
(3)	Good
(6)	Fair (default)
(9)	Poor

The General Condition classification is dependent on existing subjective data from past inspections. This information is most easily obtained from Phase I inspection reports on the dams in question. On the first page of each report there is a "Brief Assessment" section which outlines, in sentence form, the general condition of the dam at the time of inspection. Examples are:

"Generally, this dam is in fair condition."

"The dam itself is in poor condition."

"The projects are in excellent to good condition."

These statements can be used to find the weighting factor. If the dam has been re-inspected or if conditions have changed since the Phase I

inspection report was issued, then the weighting factor should be changed to be in accordance with the new information. If the dam in question was not inspected during Phase I, then the information should come from Division of Waterways files. If no information is available on a particular dam, it should be considered in fair condition and given a default value of six.

Rankings in this category give an overall opinion on the condition of a dam. They can be heavily influenced by the judgment of the inspectors and have the ability to change the overall ranking of a dam relative to others in a group if improvements or deterioration are noted over time.

Exhibit XI

SEEPAGE

Weighting Factor	Seepage
(0)	None
(3)	Slight (default value)
(6)	Moderate
(9)	High

The information needed for the Seepage classification is also obtained from the "Brief Assessment" section of the Phase I reports or from past Division of Waterways inspections. According to the study cited earlier[2], about one-third of all dam failures are in some way related to seepage problems. If no information is available, it should be assumed that there is some slight seepage. A default value of three should be assigned.

Height (Exhibit XII) and Capacity (Exhibit XIII) are two separate categories needed for the risk assessment. This information can be obtained from Division of Waterways records, the National Dam Inventory, or the Phase I inspection reports. Both are also used to determine the size of a dam which in turn is needed for the spillway classification. It should be noted

Exhibit XII

HEIGHT

Weighting Factor	Height (feet)
(0) Very low	0-14
(3) Low	15-39
(6) Moderate	40-99
(9) High	100+

Exhibit XIII

CAPACITY

Weighting Factor	Capacity (acre - feet)
(0) Very Low	0-14
(3) Low	15-999
(6) Moderate	1,000-49,999
(9) High	50,000+

that size is not given a value that directly affects the risk assessment score. The size classification is only used as a means to evaluate the spillway classification.

This assessment methodology uses the size classification system developed and used by the Corps of Engineers in Phase I Inspections.[12] Any dam which was inspected during Phase I will already have been sized. This information is in the "Brief Assessment" section of the Phase I reports. If a dam was not inspected during Phase I, Exhibits XII and XIII, can be used to determine size as follows:

If both Height and Capacity have weighting factors less than three, then Size is Small. Numerical value is one (1).

If either Height or Capacity have weighting factors equal to six, then Size is Intermediate. Numerical value is two (2).

If either Height or Capacity have weighting factors equal to nine, then size is Large. Numerical value is three (3).

The Hazard Potential classification is an important part of the risk assessment. It was weighted more heavily than the other categories so that high hazard dams would tend to be inspected more often. In most cases, dams have already been given a Hazard Code by the Corps of Engineers. These same codes are used in the risk assessment. The following tables detail how weighting factors are assigned according to the Phase I Hazard Code. The information needed can be found in either the National Dam Inventory Data or the "Brief Assessment" section of the Phase I inspection reports.

If a dam was not inspected or inventoried during the Corps' Phase I program, Exhibits XIV, XV, and XVI can be used to find the Hazard Potential

Exhibit XIV

LOSS OF LIFE

Numerical Value	Extent of Development
(1)	Low (No Habitable Structures)
(2)	Significant (Any Habitable Structures)
(3)	High (More than a Few Dwellings)

Exhibit XV

ECONOMIC LOSS

Numerical Value	Extent of Development
(1)	Minimal (Undeveloped or Occasional Agriculture)
(2)	Appreciable (Notable Industry or Agriculture)
(3)	Excessive (Extensive Business, Industry, Agriculture, or Water Supply)

Exhibit XVI

HAZARD POTENTIAL

Weighting Factor	Hazard Potential
(4)	Low (Phase I Hazard Code 3)
(8)	Significant (Phase I Hazard Code 2)
(12)	High (Phase I Hazard Code 1)

Note: If a dam was not inventoried by the Corps of Engineers, use the following criteria along with the loss of life and economic loss weighting factors.

If both loss of life and economic loss numerical values are one (1), then Hazard Potential is low. Weighting factor is four (4).
If either loss of life or economic loss numerical values are two (2), then Hazard Potential is Significant. Weighting Factor is eight (8).
If either loss of life or economic loss numerical values are three (3), then Hazard Potential is High. Weighting Factor is twelve (12).

Note: Hazard Potential weighting factors are also needed with Exhibit XVII for the Spillway classification.

weighting factor. Exhibits XIV and XV use the hazard potential categories developed by the Corps of Engineers. Hazard Potential is a function of both loss of life potential and economic loss potential. When defining the Hazard Potential for a dam, one should be as conservative as possible. If no information is available in existing files, the extent of development can be estimated by evaluating the potential inundation area with a topographic map. Division of Waterways files give the topographic map number for each dam recorded.

The spillway classification is important. More than 50 percent of the U. S. dams inspected during the National Inspection of Dams Program had deficient spillways.[3,9] About 30 percent of all dam failures are the result of overtopping caused by inadequate spillways.[2] The Bureau of Reclamation and the Corps of Engineers have very strict guidelines with regard to spillway capacity. The risk assessment procedure presented here is consistent with those guidelines.

Exhibit XVII

SPILLWAY CLASSIFICATION

Hazard Potential	Size	Spillway Design Flood
Low (4)	Small (1)	50 to 100 yr. frequency flood
	Intermediate (2)	100 yr. flood to 1/2 PMF*
	Large (3)	1/2 PMF to PMF
Significant (8)	Small (1)	100 yr. flood to 1/2 PMF
	Intermediate (2)	1/2 PMF to PMF
	Large (3)	PMF
High (12)	Small (1)	1/2 PMF to PMF
	Intermediate (2)	PMF
	Large (3)	PMF

Note: *PMF = Probable Maximum Flood

The Spillway classification is based on both the Size and Hazard classifications. On the basis of those two ratings, the Spillway Design Flood (SDF) is chosen from Exhibit XVII. The actual spillway must be checked to determine if it will pass the SDF. If it will pass the SDF, it is given a score of zero (0) on the risk assessment. If it will not pass the SDF, it is given a score of nine (9).

Once again, any dam which was inspected during the Corps of Engineers Phase I inspection program will have already had it's spillway evaluated. A summary of the results is presented in the "Brief Assessment" section of the Phase I report. Spillway calculations are often complicated and lengthy. They require field trips to the dam site and historical meteorological and hydrologic data. Since this valuable work has already been done during the Phase I program, it makes sense to use the results in the risk assessment. New calculations of spillway adequacy should be performed as part of each dam inspection.

Most dams in Massachusetts do not have engineered spillways simply because of their age. It is therefore likely that most existing spillways would not pass the SDF. Some spillways which may have been adequate at the time of construction might not be so today. Downstream development may have increased the Hazard rating of a dam. Upstream development may mean a new SDF would have to be assigned which would be larger than the old SDF. If spillway calculations are not available (i.e, the dam was not inspected during Phase I), a default value of eight (8) should be used for the risk assessment. This value reflects both the assumptions on older spillways

stated above and the seriousness with which the dam safety officials view spillway adequacy.

A RISK ASSESSMENT EXAMPLE

In order to clarify the preceding presentation of the risk assessment procedure, an example is presented here. Despite the amount of data and the number of Exhibits that are necessary, it takes only a few minutes to perform the analysis. The Quabbin Reservoir's Winsor Dam in Ware was chosen because it was one with which readers of this report are probably familiar. Because it is well engineered, relatively new compared to other dams in the Commonwealth, and obviously critical to the security of the metropolitan water supply, it is in good condition. It will, however, serve to illustrate the risk assessment procedure.

Exhibit XVIII lists the classification categories, the data source, and the weighting factor source (from this report). The only sources of data needed were the Phase I inspection report for this dam and National Inventory of Dams data. All of the information could have been obtained strictly from the Phase I report.[14]

The risk assessment total, forty-two (42), in this case, means nothing by itself. It should be viewed relative to the ratings of other dams for inspection prioritization purposes. Obviously, a high hazard dam like the Quabbin Winsor Dam should be inspected often. It is, however, in "good to

Exhibit XVIII

Risk Assessment Example

QUABBIN WINSOR DAM
WARE, MA

CLASSIFICATION	WEIGHTING FACTOR
AGE: (46 years) Source: National Inventory, Exhibit IX	(8)
GENERAL CONDITION: (Good to Excellent) Source: Phase I Brief Assessment, Exhibit X	(4)
SEEPAGE: (None) Source: Phase I Brief Assessment, Exhibit XI	(0)
HEIGHT: (155 ft.) Source: National Inventory, Exhibit XII	(9)
CAPACITY: (1,833,000 acre-feet) Source: National Inventory, Exhibit XIII	(9)
HAZARD POTENTIAL: (High) Source: Phase I Brief Assessment, Exhibit XVI, or: Exhibits XIV, XV, and XVI	(12)
SPILLWAY: (Adequate for Spillway Design Flood) Source: Phase I Brief Assessment	(0)
TOTAL:	(42)

excellent" condition so it will score lower than other dams in the high hazard category.

RISK ASSESSMENT AND DATA BASE MANAGEMENT

A sample of the risk assessment procedure has been given. As explained previously, there are seven variables involved in the ranking process. It is not a rigid, unalterable system. For example, the Division could use the risk assessment methodology to rank all the high hazard dams as one group, all the significant hazard dams as a second group, and all the low hazard dams as a third group to prioritize dams within individual categories instead of prioritizing all dams at once. This is where a data base management system becomes useful, specifically, the spread sheet systems of the type available for micro computers. The recommendations for the uses of the rankings developed with the hazard assessment methodology are presented in the next chapter.

Chapter 4

Recommendations

The following chapter presents our recommendations for upgrading the Massachusetts dam safety program, using the risk assessment methodology to prioritize the dams for the order, frequency, and level of inspection.

DAM INVENTORY

To begin with, a comprehensive dam inventory is needed. This inventory must be compiled in a form that is readily accessible. Given its size (there are an estimated 3000+ dams in the state) it must be computerized. Inventory activities should start with the 1151 dams covered in the Corps of Engineers' study. Those dams covered by M.G.L. Chapter 253 because they "could endanger property or safety" insofar as they can be readily identified, should be inventoried next. (A rough evaluation could be done using USGS topographic maps to get an estimate of downstream development, with later visual inventorying to confirm or change the initial evaluation.)

Basic inventory data for each dam should include:

location
name of dam (if any)
stream or river name
owner
owner's address
operator (if other than owner)
operator's address
date of construction
height
storage (maximum capacity)
type of dam
date of last inspection

If the dam is subject to the provisions of Chapter 253, (See page 8 for the definition of those dams which are subject to M.G.L. Chapter 253), the following additional information must be added to the inventory (for use in the risk assessment methodology):

date of construction
general condition (from last inspection)
seepage
height } or "size"
capacity
potential for loss of life } "hazard potential"
potential for property damage
desired spillway capacity (Spillway Design Flood)
actual spillway capacity

Depending on the computer system and software package used these could be entered as one complete data set or two separate data sets.

SOFTWARE

Software packages known as "spread sheets" and "data base managers", which are readily available for microcomputers, are well suited to entering, editing, and handling inventory data such as this. These packages are becoming available for larger computers as well. The software is easy to use. It does not require specialized computer training. Furthermore the software is designed to allow manipulations of the data in the inventory for analysis purposes - exactly the sort of calculations performed by the risk assessment methodology.

HARDWARE

Some of the advantages and disadvantages of using a microcomputer in the dam safety inspection program for the inventory would be:

Advantages

- ready accessibility and user friendliness
- sense of "ownership" and responsibility for the process and data (large (remote) computers sometimes evoke we-them relationships, especially in occasional users)
- availability for other tasks such as word processing and routine calculations (such as calculating spillway capacities)

Disadvantages

- the inventory software may not be as versatile due to limited microcomputer memory size.
- data storage and retrieval may be cumbersome due to limited storage capacity of floppy disks.

The use of a larger computer (e.g. via terminal) would overcome the disadvantages (assuming software availability), perhaps at the cost of the first two advantages listed above. The loss of these advantages is not trivial: psychological factors are very important to

the acceptance and use of computers by agency personnel. We recommend the purchase of a microcomputer with large data storage capacity for the data management activities.

The risk assessment methodology is a simple manipulation of the inventory data. Thus a risk assessment for all the dams in the inventory (or a subset of them) can be performed as often as desired. We recommend that a risk assessment be performed as soon as possible and once each year thereafter in order to categorize and prioritize dams for inspection.

CH.722
REQUIREMENT

A basic classification of dams is required by Chapter 253 (as amended by Ch. 722, Acts of 1979):

> Said regulations shall classify dams according to the potential for damage to life or property, taking into consideration factors such as height, type of structure, condition of structure, volume of the impoundment, extent of development downstream and other factors deemed appropriate by the commissioner.

The risk assessment methodology presented in this report is designed to do much more than just satisfy this requirement. The risk assessment methodology gives each dam a priority ranking. This ranking could be used to order dam inspections, starting with the dam receiving the highest score and proceeding down the list. Such an approach would be acceptable if the dams were only going to be inspected once. Dams must be inspected repeatedly however; and the most risky should be inspected more frequently than the least risky.

USE OF RISK ASSESSMENT

We recommend that the risk assessment methodology be used to classify the dams into three categories for subsequent inspections. (Each category of dams will be assigned a different inspection frequency.)

To break the dams into three categories, two arbitrary cutoff points must be specified. The cutoff points chosen will determine the number of dams in each category, and hence the number of inspections to be conducted each year (and therefore the number of inspectors required by the agency). Thus the cutoff points must be chosen with care.

The Corps of Engineers rated dams according to hazard only, not risk. Of the 1151 dams included in their inventory they rated 245 as "high" hazard, 425 as "significant" hazard and 481 as "low" hazard.

The high risk category for the purpose of dam inspections should contain approximately all of the dams identified as high hazard as well as dams with lesser hazard ratings but higher overall risk due to other characteristics such as condition or spillway capacity. Our experience from using the risk assessment methodology on a sample of 20 Massachusetts dams suggests a cutoff between the high and medium categories of 41-43 and a cutoff between the medium and low categories of 35-37.

Without having a complete inventory and a risk assessment for all dams, it is difficult to say how many

dams will be placed in each category using these cutoff points. For the purposes of projecting the number of inspections and consequent staffing we have used estimates roughly based on the Corps of Engineers' categories, scaled to a total of 1600 dams: 350 high, 550 medium, and 700 low.

TYPES OF INSPECTIONS

We recommend that two types of inspections be conducted: Formal Technical Inspections and Informal Maintenance Inspections. The Technical Inspections should be conducted by a multidisciplinary team of inspectors. Technical inspections are intended to be thorough inspections, with each component of the inspection performed by an expert. The inspectors on the Technical Inspections should be looking for the not-so-obvious deficiencies and the potential deficiencies as well as the obvious. The frequencies of the Technical Inspections are related to the risk associated with each dam:

Risk category	Frequency of Technical Inspections
high	once per year
medium	once every two years
low	once every five years

Maintenance Inspections cover the same items as the Technical Inspections. Each Maintenance Inspection should be conducted by a single dam inspector who should have a

general civil engineering background. The inspector's charge on Maintenance Inspections is to look for obvious changes in a dam's condition that have occurred since the last inspection. If the changes are serious enough the Technical Inspection schedule for the dam might have to be changed, or a Special Inspection scheduled.

Maintenance Inspection frequencies have been assigned so that high risk dams are inspected twice per year (one Technical and one Maintenance). Medium risk dams are inspected once per year (every other inspection is a Technical Inspection). Low risk dams are inspected once per year as well. (Every fifth inspection is a Technical Inspection.)

Risk Category	Frequency of Maintenance Inspections
high	once per year
medium	once every two years
low	four times every five years

Obviously the scheduling of the Technical and Maintenance Inspections must be coordinated.

The total inspections each year can be estimated as:

Risk Category	Est. No. of Dams	Inspections per Year Formal Tech.	Informal Maint.
high	350	350	350
medium	550	275	275
low	700	140	560
Total	1600	765	1185

STAFFING

Staffing requirements for the Maintenance Inspections amount to six person-years, assuming 230 working days per year after sickness and vacations are taken into account and assuming one inspection per day. Actually, most maintenance inspections will take considerably less than one day, but allowing for office duties and inclement weather, an average of one per day is an acceptably conservative estimate.

Staffing estimates for the Technical Inspections are more difficult to estimate. The Technical Inspection team should include:

Structural Engineer

Hydraulic Engineer

Mechanical Engineer (where appropriate)

Electrical Engineer (where appropriate)

Diver

Geologist

Each discipline is discussed separately below.

Structural Engineer. The structural engineer is the logical team leader. As such he or she will need to schedule and coordinate the activities of the other specialists and be responsible for the office duties as well as being responsible for the greatest portion of the inspection protocol. Estimate 1 1/2 days per dam.

Hydraulic Engineer. The hydraulic engineer will need to calculate the design flood (spillway design capacity) for each dam during its first inspection. (These have already been calculated for the 369 dams inspected by the Corps.) The actual spillway capacity must be calculated each time, but for most subsequent inspections it will not change much from the first inspection. Estimate 1/2 day per dam (more for first five years, less than 1/2 day after that).

Electrical Engineer. The Corps of Engineers identified 38 dams whose primary purpose was hydroelectric power generation. Estimating that there are 100 dams with hydropower (either as a primary or secondary purpose) and estimating 1/2 day per dam and assuming that dams with hydropower will be inspected once each year results in manpower needs of 50 days per year for an electrical engineer.

Geologist. The services of a geologist are needed on every Technical Inspection. Estimate 1/2 day per dam.

Diver. A diver is probably needed only once every two years for each high and medium risk dam and once every five years for the low risk dams. Estimate 1/2 day per dam but double the estimate since divers should not dive alone.

Overall Estimates

	Days/dam x	Dams/yr	= Days/yr
Structural Engineer	1 1/2	765	1,147
Hydraulic Engineer	1/2	765	382
Mechanical Engineer	1/4	765	191
Electrical Engineer	1/2	100	50
Geologist	1/2	765	382
Diver	1	590	590

These estimated work loads should be met by hiring five structural engineers, two hydraulic engineers, one mechanical engineer and two geologists for the dam safety inspection program itself. We recommend contracting out, or working out cooperative arrangements with other agencies, for the remaining specialties. These estimates do not include travel time estimates. Specific recommendations dealing with travel and scheduling are outlined below.

STAFFING SUMMARY

The staffing recommendations for the dam safety

inspection program are summarized below:

- 5 dam inspectors (for the informal Maintenance Inspections) (civil engineers)
- 5 structural engineers
- 2 hydraulic engineers
- 1 mechanical engineer
- 2 geologists
- 1 clerical

In addition arrangements must be made to obtain the services of an electrical engineer and divers at times to be scheduled by the inspection team leaders.

REGIONAL BASED INSPECTORS

Due to the inefficiency of time spent travelling, the key dam safety inspection personnel, especially the Dam Inspectors and the Structural Engineers, should be located in regional offices. Regionally based inspectors will allow more dams to be visited each day. It must be recognized, however, that scheduling Technical Inspections will be a difficult task since travel time, frequency of inspection, and availability of specialized personnel must all be taken into account. Each regional office should have its own microcomputer for its data management activities.

USE OF RANKINGS

It is tempting to use the rankings from the risk assessment methodology to order the dams in each category for inspection. Our recommendation is that dam

inspections be ordered to give the most efficient use of personnel time. Risk assessment methodologies are not as precise as they appear to be. A one or two point difference in risk rating is probably not statistically significant. Therefore we recommend treating all dams within a class equally (unless there are some high category dams with extremely high ratings) and concentrating instead on achieving the most efficient use of resources. Efficient use of resources to minimize time spent traveling between dams will allow all dams to be inspected more often.

DISCUSSION

One point which comes across clearly in the literature and in the recommendations of those concerned with dam safety inspections is the importance of having multidisciplinary inspection crews. Dam safety inspections must certainly look for the obvious deficiencies. Equally importantly, they must ferret out the non-obvious problems. Thus, in the end, the inspections can be no better than the people performing them. The best way to achieve this is to significantly upgrade the perceived importance of dam safety inspection at the legislative, executive and agency levels. Experience shows that, in general, the more important the function, the better the personnel assigned to it and the better they perform.

The dam safety inspection staff needed is a subjective judgment. We used values of 350, 550 and 700 dams in the high, medium and low risk categories, respectively, based in large measure on the Corps of Engineers inventory results. Any shifting of dams from higher to lower categories (e.g. to 300, 550, 750) will decrease the inspection staff "required" since dams in lower risk categories are not inspected as frequently. An accurate count of the number of dams the program is responsible for, and their classifications, will not be available until the inventory recommended above is completed.

In the end, the ultimate size, and composition of the Massachusetts dam safety inspection program is a political balancing of the safety provided versus the economic cost of the program. Unfortunately there is no "Best Dam Safety Inspection Program." We have presented guidelines for frequency of inspection, contents of inspection, and inspection staffing based on our review of existing dam safety programs, recommendations from public agencies, and our understanding of the Massachusetts situation. Translation of these guidelines into actual numbers cannot be done until an adequate inventory is available. We have presented an estimate based on the best inventory available, that of the Corps of Engineers from 1978-81. After an adequate inventory becomes

available the staffing guidelines presented on pages 44-47 can be used with inspection frequencies recommended on pages 42-44 to calculate the dam safety program staffing needs.

ADDITIONAL RECOMMENDATIONS AND COMMENTS

- Hazard assessment has traditionally focused on the downstream damages. The losses to the public from dam failure can also be significant if the dam provided a major portion of a community's water supply. Water supply considerations have been added to the hazard potential determination (Exhibit XV) for this reason.
- Notification of owners and follow-up on repair of deficiencies is just as important as the dam inspection itself. The dam safety program must adopt and implement much stronger procedures in this area.
- All of the recommendations in this report, except those dealing with staffing, could be implemented by the Department of Environmental Management with the regulation-writing authority it now has. Chapter 253 (as amended in 1979) directed that regulations be prepared. This has not been done. Regulations should be prepared as soon as possible.
- Cooperative programs to share U. S. Corps of Engineers technical personnel should be investigated as a means of obtaining the specialized expertise for the dam safety inspection program.

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Appendix A - DAM SAFETY INSPECTION PROTOCOLS

These recommended protocols are to be used for all inspections. When a multidisciplinary team performs the inspection each team member would be responsible for his specific portion of the protocol. When the inspection is conducted by one or two dam inspectors all items in the protocol should be addressed but the level of expertise and quality of evaluation will of course be less. Each inspection should be as comprehensive as possible, given the expertise of the inspection team.

Categories which do not apply to a given dam may be omitted.

Recommended Inspection Protocol for Examination of EMBANKMENT DAMS

General Condition of Dam ________________________________
(To be filled in at end of inspection)

UPSTREAM FACE

Slope protection
Erosion-beaching
Vegetative growth
Settlement
Debris
Burrows or burrowing animals
Unusual conditions

DOWNSTREAM FACE

Signs of movement
Seepage or wet areas
Vegetative growth
Channelization
Condition of slope protection
Burrows or burrowing animals
Unusual conditions

ABUTMENTS

Seepage
Cracks,joints, and bedding planes
Channelization
Slides
Vegetation
Signs of movement

CREST

Surface cracking
Durability
Settlement
Lateral movement(alignment)
Camber

SEEPAGE AND DRAINAGE SUMMATION

Location(s)
Estimated flow(s)
Color(staining)
Erosion of outfall
Toe drain and relief wells

FOR EACH AREA OF SIGNIFICANT SEEPAGE

Method of measurement
Amount
Change in flow
Clearness of flow

- Color
- Fines
- Condition of measurement devices
- Records

OTHER

PERFORMANCE INSTRUMENTS
(These should be examined to ensure that the system is maintained in a manner such that dependable and continued readings can be obtained)

Piezometer well

- Well
- Frostfloor
- Ventilation
- Gages
- Piping
- Security

Surface settlement points
Crossarm devices
(deviation, station, and offset)
Reservoir-level gage
Ice-prevention system
Other

SPILLWAY

APPROACH CHANNEL

Vegetation (trees, willows, etc.)
Debris
Slides above channel
Channel side slope stability
Log boom
Slope protection

CONTROL STRUCTURES (OBSERVED OPERATION)

Apron

Surface condition
General condition of concrete
Movement
Settlement
Joints
Cracks

Crest

Surface condition
General condition of concrete
Cracks or areas of distress
Signs of movement

Walls

Surface condition
General condition of concrete
Movement(offsets)
Cracks or areas of distress
Settlement
Joints
Drains
Backfill

Gates

Condition
Hoist equipment
Control equipment

Bridge

Condition of piers
Surface of roadway slab
Structural condition of slab
and beams
Bridge bearings
Overall condition

CHUTE

Debris
Walls

Surface condition
General condition of concrete
Movement(offsets)
Settlement
Joints

Cracks or areas of distress
Condition of backfill

Floor

Surface condition
General condition of concrete
Movement
Settlement
Joints
Drains
Cracks

Drainage gallery

General condition of concrete
Movement(misalignment of gallery)
Cracks
Drains

Amount of flow
Location of seeping drains

Ventilation
Lighting

STILLING BASIN

Debris in basin
Walls

Surface condition
General condition of concrete
Movement (offsets)
Settlement
Joints
Cracks or areas of distress
Condition of backfill

Floor (if visible)

Surface condition
Condition of concrete
Cracks or areas of distress
Movement
Joints
Erosion

OUTLET CHANNEL

Slope protection
Stability of side slopes
Vegetation or other obstructions

OTHER

OUTLET WORKS

INLET WORKS(if visible)

Trashracks
Trashrack concrete structure
Intake bulkhead

General condition
Protective coating
Seals

Inlet and upstream tunnel
Gate structure

General condition
Leakage
Metalwork(air vent, bonnet cover, gate stems, watertight access door)

General condition
Protective coating

EMERGENCY CONTROL FACILITY

Security

Gate

General condition
Protective coating
Cavitation
Leakage (closed)
Exercising frequency
Operation at time of examination

Control system

Mechanical
Electrical

Access

Concrete
Metalworks
Ventilation
Lighting
Leakage

Gate shaft

Concrete
Leakage
Metalwork(gate items, stem handling equipment)

General
Protective coating

Gate hoist shelter house

General condition
Reservoir-level gage

OUTLET CONDUIT

Metalwork

General condition
Protective coating
Cavitation

Concrete

General condition
Leakage

Ventilation
Lighting

SERVICE CONTROL FACILITY

Valve or gate house

General condition
Security
Gate(s)

General condition
Protective coating
Cavitation
Leakage
Exercising frequency
Operation of gates at time of examination

Valve(s)

General conditions
Protective coatings
Cavitation
Leakage(closed)
Creep
Exercising frequency
Operation of valves at

time of examination

Control system for gates
and valves

Mechanics
Electrical
Operating instructions

OTHER

STILLING BASIN

Debris in basin
Walls

Surface condition
Concrete
Joints
Cracks
Backfill
Movement

Floor (if visible)

Surface condition
Stainless steel liner
Concrete
Joints
Signs of deterioration
Cracks
Cavitation
Movement

OUTLET CHANNEL

Vegetation
Gravel bars, etc.
Riprap
Stability of side slopes

OTHER

POWER FEATURES

(if related to safe operation or structural integrity of dam)

INTAKE STRUCTURE

TRASHRACK

BULKHEAD GATE

INTAKE GATES

INTAKE GATE HOIST

GANTRY CRANE

Mechanical
Electrical
Paint
Operating instructions
Operation during examination
Storage area

PENSTOCK

Powerplant structure

Ceilings
Deck
Walls
Substructure

TAILRACE

Draft tube closure structure
Draft tube bulkhead
Gantry crane

STANDBY POWER UNIT

Condition
Exercising frequency
Automatic features
Operation during examination

RESERVOIR

(The region around the reservoir should be examined for indications of problems which might affect the safety of the dam or reservoir)

LOG BOOM

LANDSLIDES

(individual designation,
location for identification,
and description)

OTHER

ACCESS ROAD

(If the safe operation of the dam depends on adequate and safe means of access)

CONDITION OF

PAVEMENT

DITCHES

BRIDGE

General condition
Vegetation at abutments
and piers
Bridge supports

- Foundations
- Substructures-piers
- Bridge bearings
- Moving parts
- Accumulation of birds nests, etc.
- Visual examination of scour protection
- Protective coatings

Main supporting members

- Deteriorated and/or damaged members
- Protective coating

Bridge deck

- General condition
- Drainage
- Expansion joints
- Guardrails
- Signing
- Live load capacity

LOSS POTENTIAL (DURING EMERGENCY)

OTHER

GEOLOGY

SITE GEOLOGY

Dam

Spillway

Outlet works

Abutment (left)

Abutment (right)

Reservoir

SEEPAGE

Damsite

Downstream channel

Other

PHYSICAL FEATURES

Faulting

Clay seams

Depressions

Sinkholes

Bedding planes

Shear seams

Solutioning

Other

SEISMICITY

Surface rupture

Ground tilting

Liquefaction potential

Settlement

Seiches

LANDSLIDES

Reservoir

Damsite

Downstream channel

Other

OTHER COMMENTS AND OBSERVATIONS NOT COVERED ABOVE:

Recommended Inspection Protocol for Examination of CONCRETE DAMS

General Condition of Dam ______________________________
(to be filled in at end of inspection)

DAM

UPSTREAM FACE

DOWNSTREAM FACE

General condition
Seepage

CREST

Offsets
Roadway
Walks
Parapet wall
Lighting, etc.

GALLERIES

Concrete
Metalwork
Electrical
Ventilation
Seepage
Drains and drainage(all drains should be open)

Frequency of cleaning or probing

FOUNDATION TUNNELS

General
Seepage

INSTRUMENTATION

Structural
Seepage

ICE-PREVENTION SYSTEM

OTHER

ABUTMENTS

	Left	Right
FOUNDATION AT DOWNSTREAM TOE OF DAM		

Leakage around dam

- Location
- Amount
- Measurement method

OTHER

SPILLWAY

CONTROL STRUCTURES

Crest
Orifices

GATES AND CONTROLS

Type of gate
General condition
Protective coating
Leakage (closed)
Exercising frequency
Operation of gates at time of examination

CONTROLS FOR GATES

Mechanical

- Hoists
- Wire ropes
- Protective coatings

Electrical

- Remote control
- Power supply
- Standby power
- Operation instructions

WEATHER DOORS

General condition
Protective coating
Exercising frequency
Operation at time of examination

CONTROLS FOR WEATHER DOORS

Mechanical

- Hoists
- Wire ropes

Protective coatings

Electrical

STOPLOGS

General condition
Protective coating
Seals

STILLING BASIN

Walls
Floor
Weir
River channel below basin

Riprap
Erosion
Vegetation

CHUTE OR TUNNEL

Debris
Walls

Surface condition
General condition of concrete
Movement(offsets)
Settlement
Joints
Cracks or areas of distress
Condition of backfill

Floor

Surface condition
General condition of concrete
Movement
Settlement
Joints
Drains
Cracks

OTHER

OUTLET WORKS

INTAKE

Trashrack
Concrete

OUTLET CONDUIT

Metalwork
Cavitation

CONTROL FACILITIES

Gatehouse
Crane
Gate and controls

- General condition
- Protective coating
- Cavitation
- Exercising frequency
- Operating at time of examination
- Control system
  - Remote
  - Auxiliary power
  - Mechanical
  - Electrical
  - Operating instructions

Weather barrier

- General condition
- Protective coating
- Exercising frequency
- Operation at time of examination
- Control

Bulkhead

- Availability
- General condition
- Protective coating
- Seals

STILLING BASIN

Debris in basin
Walls

- Surface condition
- Concrete
- Joints
- Cracks
- Backfill
- Movement

Floor(if visible)

- Surface condition
- Stainless steel liner

Concrete
Joints
Signs of deterioration
Cracks
Cavitation
Movement

OUTLET CHANNEL

Vegetation
Gravel bars, etc.
Riprap
Stability of side slopes

OTHER

POWER FEATURES
(if related to safe operation or structural integrity of dam)

INTAKE STRUCTURE

TRASHRACK

BULKHEAD GATE

INTAKE GATES

INTAKE GATE HOISTS

GANTRY CRANE

Mechanical
Electrical
Paint
Operating instruction
Operation during
examination
Storage area

PENSTOCK

Powerplant structure
Ceilings
Deck
Walls
Substructure

TAILRACE

Draft tube closure structure
Draft tube bulkhead
Gantry crane

STANDBY POWER UNIT

Condition
Exercising frequency
Automatic features
Operation during examination

OTHER

RESERVOIR

(The region around the reservoir should be examined for indications of problems which might affect the safety of the dam or reservoir)

LOG BOOM

RESERVOIR LEVEL
GAGE

LANDSLIDES

(individual designation,
location for identification,
and description)

OTHER

ACCESS ROAD

(If the safe operation of the dam depends on adequate and safe means of access)

CONDITION OF
PAVEMENT

DITCHES

BRIDGE

General condition
Vegetation at abutment
and piers
Bridge supports

Foundations
Substructures-piers
Bridge bearings
Moving parts
Accumulation of
birds` nests, etc.
Visual examination
of scour protection
Protective coating

Main supporting members

Deteriorated and/or
damaged members

Protective coating

Bridge deck

General condition
Drainage
Expansion joints
Guardrails
Signing
Live load capacity

LOSS POTENTIAL(During Emergency)

OTHER

GEOLOGY

SITE GEOLOGY

Dam

Spillway

Outlet works

Abutments Left Right

Reservoir

SEEPAGE

Damsite

Downstream channel

Other

PHYSICAL FEATURES

Faulting

Clay seams

Depressions

Sinkholes

Bedding planes

Shear seams

Solutioning

Other

SEISMICITY

Surface rupture

Ground tilting

Liquefaction potential

Settlement

Seiches

LANDSLIDES

Reservoir

Damsite

Downstream channel

Other

OTHER COMMENTS AND OBSERVATIONS NOT COVERED ABOVE:

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